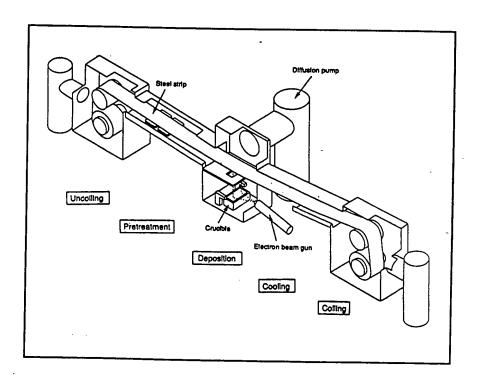
HANDBOOK OF DEPOSITION TECHNOLOGIES FOR FILMS AND COATINGS

Science, Technology and Applications
Second Edition



Edited by Rointan F. Bunshah

NOYES PUBLICATIONS

Appendix C

Goldwasser *et al.*Application No.: 08/847,967

Copyright © 1994 by Noyes Publications No part of this book may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage and retrieval system, without permission in writing from the Publisher. Library of Congress Catalog Card Number: 93-30751 ISBN: 0-8155-1337-2 Printed in the United States

Published in the United States of America by Noyes Publications Fairview Avenue, Westwood, New Jersey 07675

109876543

Library of Congress Cataloging-in-Publication Data

Handbook of deposition technologies for films and coatings / edited by Rointan F. Bunshah. -- 2nd ed.

Rev. ed of: Deposition technologies for films and coatings. c1982.

Includes bibliographical references and index.

ISBN 0-8155-1337-2

1. Coating processes.

I. Bunshah, R. F. (Rointan Framroze)

II. Title: Deposition technologies for films and coatings.

TP156.C57H38 1994

667' .9--dc20

93-30751

CIP

Appendix C

Goldwasser et al. Application No.: 08/847,967

Contents

1	Deposition Technologies: An Overview Rointan F. Bunshah	1
1.0		4
2.0	114111000011014	
3.0		
4.0		4
5.0	THE VALUE DEPOSITION (DVD) DEPOSES	
6.0	TERMINOLOGY	6
7.0		_
B.0	GAS JET DEPOSITION WITH NANO-PARTICLES	10
9.0	MICROSTRUCTURE AND PROPERTIES	12
•	SINGUE I CATURES OF DEPOSITED MATERIALS	
0.0	AND GAPS IN UNDERSTANDING	14
0.0	O O TIME AFFEIGATIONS	
	· · · · · · · · · · · · · · · · · ·	
	The state of the control of the state of the	
	I notion and wear	4.0
	materials Conservation	4-
	isis sauma rouis	
	Transact Tuels	40
		40
	10.9 Electrical Uses	10
		10

ΧV

Goldwasser *et al.*Application No.: 08/847,967

Contents xvi

11.0	"FRONTIER AREAS" FOR THE APPLICATION OF THE	
	PRODUCTS OF DEPOSITION TECHNOLOGY	18
12.0	SELECTION CRITERIA	20
13.0	SUMMARY	22
APP	ENDIX 1: DEPOSITION PROCESS DEFINITIONS	23
	Conduction and Diffusion Processes	23
	Chemical processes	24
•	Wetting Process	24
	Spraying Processes	
REF	ERENCES	
2	Plasmas in Deposition Processes	29
	John A. Thornton and Joseph E. Greene	
1.0	INTRODUCTION	29
2.0	PARTICLE MOTION	
	2.1 Mean Free Path and Collision Cross Sections	
	2.2 Free Electron Kinetic Energy in a Plasma	32
	2.3 Electron Energy Distribution Functions	
	2.4 Collision Frequencies	
3.0	COLLECTIVE PHENOMENA	
	3.1 Plasma Sheaths	
	3.2 Ambipolar Diffusion	
	3.3 Plasma Oscillations	
4.0	PLASMA DISCHARGES	
	4.1 Introduction	
	4.2 Ionization Balances and the Paschen Relation	
	4.3 Cold Cathode Discharges	
	4.4 Magnetron Discharges	
	4.5 RF Discharges	
5.0	PLASMA VOLUME REACTIONS	
	5.1 Introduction	61
	5.2 Electron/Atom Interactions	
	5.3 Electron/Molecule Interactions	62
	5.4 Metastable Species	
	5.5 Applications of Volume Reactions	66
6.0	SURFACE REACTIONS	
	6.1 Introduction	
	6.2 Ion Bombardment	
•	6.3 Electron Bombardment	
	6.4 Glow Discharge Surface Cleaning and Activation	
REFE		77

3	Surface Preparation for Film and Coating
	Deposition Processes
	Donald M. Mattox
1.0	INTRODUCTION
2.0	CONTAMINATION
	2.1 necollamination
3.0	ENVIRONMENT CONTROL 85
4.0	CLEANING PROCESSES 87
	4.1 Particulate Removal 93
	4.2 Abrasive Cleaning
	4.3 Etch Cleaning
	T-T Fluxing
	4.0 Arkaine Cleaners
	4.0 Detergent Cleaning
	" Onciding Agents
	Tio Colvent Cleaning
	1.5 Oxidation Cleaning
	11 V Volume and the Color of th
	The injury of the control of the con
5.0	DITING AND COTGASSING
6.0	MOMING OF CLEANING
7.0	IN ONO CLEANING
	7.7 TOTI OCI UDDITIO
8.0	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
	o. r Generation of Plasmas
	oiz riasina Orienistry
	0.0 Dombardinelli Ellects on Surface
9.0	0.7 Spuller Cleaning and Etching
9.0 10.0	
	AS ITAM TON AND SENSITIVATION (5.5)
12.0	
13.0	1 ACCIVATION AND PRESERVATION
	OALETT
'_'	ERENCES126
4	Evanoration, Dragon Dr. H. a.s.
•	Evaporation: Processes, Bulk Microstructures and
	mechanical Properties
	Rointan F. Bunshah
1.0	GENERAL INTRODUCTION
2.0	SCOPE131

xviii Contents

	3.0	PVD PROCESSES	
		3.1 Preamble	
		3.2 PVD Processes	134
HA		3.3 Advantages and Limitations	
DE	4.0	THEORY AND MECHANISMS	
FO		4.1 Vacuum Evaporation	
	5.0	EVAPORATION PROCESS AND APPARATUS	
Sec		5.1 The System	143
	6.0	EVAPORATION SOURCES	146
Ed		6.1 General Considerations	
		6.2 Resistance Heated Sources	149
		6.3 Sublimation Sources	150
volı		6.4 Evaporation Source Materials	152
bei:		6.5 Induction Heated Sources	
res		6.6 Electron Beam Heated Sources	
up(6.7 Arc Evaporation	
tec	7.0	LASER INDUCED EVAPORATION/LASER ABLATION/	
tec		PULSED LASER DEPOSITION (PLD)	166
ext	8.0	DEPOSITION RATE MONITORS AND PROCESS CONTRO	L 168
ue,		8.1 Monitoring of the Vapor Stream	168
110		8.2 Monitoring of Deposited Mass	
		8.3 Monitoring of Specific Film Properties	
kn [,]		8.4 Evaporation Process Control	
filr	9.0	DEPOSITION OF VARIOUS MATERIALS	175
sta		9.1 Deposition of Metals and Elemental Semiconductors	
pr	•	9.2 Deposition of Alloys	
the		9.3 Deposition of Intermetallic Compounds	
CO ·		9.4 Deposition of Refractory Compounds	
		9.5 Reactive Evaporation Process	
te		9.6 Activated Reactive Evaporation (ARE)	
CC		9.7 Materials Synthesized by Evaporation-based Processes	
pı	10.0	MICROSTRUCTURE OF PVD CONDENSATES	
SI		10.1 Microstructure Evolution	
S		10.2 Texture	
D		10.3 Residual Stresses	
P		10.4 Defects	
t€	11.0	PHYSICAL PROPERTIES OF THIN FILMS	
S		MECHANICAL AND RELATED PROPERTIES	
а		12.1 Mechanical Properties	
ti	13.0	PURIFICATION OF METALS BY EVAPORATION	
а		ENDIX	
-		On Progress in Scientific Investigations in the Field of Vacuum	
fi		Evaporation in the Soviet Union	
ť	REFE	RENCES	235
•			

		5	Sputter Deposition Processes2	249
		5	John A. Thornton and Joseph E. Greene	
		1.0	INTRODUCTION	249
		1.0	1.1 Sputter Deposition Systems	252
	,		1.2 Sputter-Deposition Applications	200
			1.3 Process Implementation	200
			1.4 History of Sputter Deposition and Background Reading	25/
		2.0	SPLITTERING MECHANISMS	200
		2.0	2.1 Snuttering Rate	259
			2.2 Momentum Exchange	203
			2.3 Alloys and Compounds	200
			2.4 Sputtering with Reactive Species	209
			2.5 The Nature of Sputtered Species	. 270
			2.6 Energy Distribution of Sputtered Species	. 212
	1	3.0	SPLITTER DEPOSITION TECHNIQUES	. 2/5
	•	0.0	3.1 Planar Diode and the DC Glow Discharge	. 2/5
			3.2 Triode Discharge Devices	.279
			2.3 Magnetrons	. 200
			2.4 RF Snuttering	. 252
			3.5 Ion-Ream Snuttering	. 30 1
		4.0	CRUTTED DEPOSITION MODES	. 302
			4.1 Reactive Sputtering	. 302
	•		4.2 Bias Snuttering	JUD
	į	REF	ERENCES	311
) 				
)	•	6	lon Plating	
3			Donald M. Mattox	
,	•	1.0	INTRODUCTION	320
,		2.0	PROCESSING PLASMA	325
,		3.0	GENERATION OF PLASMAS	325
}		0.0	3.1 DC Diode Discharge	325
3			3.2 RF Discharge	329
)			3.3 Microwave Discharges	330
ļ			3.4 Flectron Emitter Discharge	აას
			3.5 Magnetron Discharges	331
5			3.6 Plasma Enhancement	აა∠
5	•	4.0	PLASMA CHEMISTRY	333
5		5.0	ROMBARDMENT FFFECTS ON SURFACES	334
)		- 7-	5.1 Collisional Effects	337
2			5.2 Surface Region Effects	342
	•		5.3 Near Surface Region Effects	343
2			5.4 Bulk Effects	343
-				

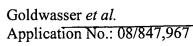
xx Contents

6.1 Thermal Vaporization 6.2 Sputtering 6.3 Vacuum Arcs 6.4 Chemical Vapor Precursors 6.4 Chemical Vapor Precursors 6.5 Vacuum Arcs 6.5 Vacuum Arcs 6.6 Vacuum Arcs 6.6 Vacuum Arcs 6.7 Vacuum V		6.0	SOUF	RCES OF DEPOSITING ATOMS	343
			6.1	Thermal Vaporization	344
1	F		6.2	Sputtering	345
1	Ţ		6.3	Vacuum Arcs	345
T.0 REACTIVE ION PLATING	_		6.4	Chemical Vapor Precursors	347
8.0 BOMBAHDMENT EFFECTS ON FILM PHOPERTIES 8.1 Effects: Adatom Nucleation 8.2 Effects: Interface Formation 8.3 Effects: Film Growth 8.4 Film Adhesion V 8.5 Film Morphology/Density b 8.6 Residual Film Stress r. 8.7 Crystallographic Orientation 8.8 Gas Incorporation 8.9 Surface Coverage to 8.10 Other Properties e 9.0 ION PLATING SYSTEM REQUIREMENTS n 9.1 Vacuum System 9.2 High Voltage Components 4 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications F 11.0 PROBLEM AREAS 5 12.0 APPLICATIONS 13.0 SUMMARY C REFERENCES 7 Chemical Vapor Deposition Jan-Otto Carlsson 1 O ESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 5 3.2 Melosics		7.0			
S.2 Effects: Interface Formation S.3 Effects: Film Growth S.4 Film Adhesion S.5 Film Morphology/Density S.6 Residual Film Stress S.7 Crystallographic Orientation S.9 Surface Coverage S.10 Other Properties S.10 Other Properties S.11 Other Properties S.11 Other Properties S.12 Other Properties S.13 Other Properties S.14 Other Properties S.15 Other Properties S.16 Other Properties S.17 Other Properties S.18 Other Properties S.19 Other	2	8.0	BOME	BARDMENT EFFECTS ON FILM PROPERTIES	347
8.3 Effects: Film Growth 8.4 Film Adhesion 9.5 Film Morphology/Density 8.5 Film Morphology/Density 8.6 Residual Film Stress 8.7 Crystallographic Orientation 8.8 Gas Incorporation 8.9 Surface Coverage 8.10 Other Properties 9.0 ION PLATING SYSTEM REQUIREMENTS 9.1 Vacuum System 9.2 High Voltage Components 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY REFERENCES 12.0 APPLICATIONS 13.0 SUMMARY REFERENCES 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 3.2 Thermodynamics 3.2 Thermodynamics 3.3 Characterist 1.4 Thermodynamics 3.3 Characterist 3.3 Characterist 3.3 Characterist 3.4 Characterist 3.3 Characterist 3.4 Characterist 3.4 Characterist 3.5 Characterist			8.1	Effects: Adatom Nucleation	347
8.4 Film Adhesion	I				
V 8.5 Film Morphology/Density b 8.6 Residual Film Stress r 8.7 Crystallographic Orientation u 8.8 Gas Incorporation tt 8.9 Surface Coverage tt 8.10 Other Properties e 9.0 ION PLATING SYSTEM REQUIREMENTS n 9.1 Vacuum System Requirements 9.2 High Voltage Components k 9.3 Gas Handling System 9.2 High Voltage Components k 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 5 11.0 PROBLEM AREAS 5 12.0 APPLICATIONS 5 13.0 SU					
b 8.6 Residual Film Stress rr 8.7 Crystallographic Orientation u 8.8 Gas Incorporation tt 8.9 Surface Coverage tt 8.10 Other Properties e 9.0 ION PLATING SYSTEM REQUIREMENTS n 9.1 Vacuum System 9.2 High Voltage Components 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 5 11.0 10 PROBLEM AREAS 5 12.0 13.0 SUMMARY 1 REFERENCES 7 Chemical Vapor Deposition Jan-Otto Carlsson <t< td=""><td></td><td></td><td>8.4</td><td>Film Adhesion</td><td> 350</td></t<>			8.4	Film Adhesion	350
b 8.6 Residual Film Stress rr 8.7 Crystallographic Orientation u 8.8 Gas Incorporation tt 8.9 Surface Coverage tt 8.10 Other Properties e 9.0 ION PLATING SYSTEM REQUIREMENTS n 9.1 Vacuum System 9.2 High Voltage Components 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 5 11.0 10 PROBLEM AREAS 5 12.0 13.0 SUMMARY 1 REFERENCES 7 Chemical Vapor Deposition Jan-Otto Carlsson <t< td=""><td>v</td><td></td><td>8.5</td><td>Film Morphology/Density</td><td> 350</td></t<>	v		8.5	Film Morphology/Density	350
R.7			8.6	Residual Film Stress	352
ti 8.9 Surface Coverage ti 8.10 Other Properties e 9.0 ION PLATING SYSTEM REQUIREMENTS n 9.1 Vacuum System 9.2 High Voltage Components k 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications F 11.0 PROBLEM AREAS S 12.0 APPLICATIONS S 13.0 SUMMARY F Toldor Carlsson ti 1.0 INTRODUCTION a 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS fi 3.1 Classification of CVD Reactions ti <td></td> <td></td> <td>8.7</td> <td>Crystallographic Orientation</td> <td> 352</td>			8.7	Crystallographic Orientation	352
ti 8.9 Surface Coverage ti 8.10 Other Properties e 9.0 ION PLATING SYSTEM REQUIREMENTS n 9.1 Vacuum System 9.2 High Voltage Components k 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications F 11.0 PROBLEM AREAS S 12.0 APPLICATIONS S 13.0 SUMMARY F Toldor Carlsson ti 1.0 INTRODUCTION a 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS fi 3.1 Classification of CVD Reactions ti <td>u</td> <td></td> <td>8.8</td> <td>Gas Incorporation</td> <td> 354</td>	u		8.8	Gas Incorporation	354
tit 8.10 Other Properties e 9.0 ION PLATING SYSTEM REQUIREMENTS n 9.1 Vacuum System 9.2 High Voltage Components 9.3 Gas Handling System k 9.4 Evaporation/Sublimation Sources g 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications F 11.0 PROBLEM AREAS S 12.0 APPLICATIONS S 13.0 SUMMARY REFERENCES 7 Chemical Vapor Deposition F 7 Chemical Vapor Deposition G 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS fi 3.1 Classification of CVD Reactions tit 3.2 Thermodynamics	tı		8.9	Surface Coverage	354
9.1 Vacuum System 9.2 High Voltage Components 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications F 11.0 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY REFERENCES Thermical Vapor Deposition Image: Proposition of CVD Carlsson Jan-Otto Carlsson It 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 1t 3.2 Thermodynamics	tı		8.10	Other Properties	355
9.2 High Voltage Components 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications F 11.0 PROBLEM AREAS 5 12.0 APPLICATIONS 5 13.0 SUMMARY C REFERENCES F 7 Chemical Vapor Deposition Jan-Otto Carlsson 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 6 3.1 Classification of CVD Reactions 1.2 Adherical	e	9.0			
k 9.3 Gas Handling System 9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY 13.0 SUMMARY 13.0 SUMMARY 14.0 REFERENCES 15.0 INTRODUCTION 15.0 IMPORTANT REACTION ZONES IN CVD 15.0 IMPORTANT ZONES I	n		9.1	Vacuum System	355
9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY 15 REFERENCES 16 7 Chemical Vapor Deposition 17 Chemical Vapor Deposition 18 Jan-Otto Carlsson 19 Jan-Otto Carlsson 10 INTRODUCTION 20 IMPORTANT REACTION ZONES IN CVD 31 DESIGN OF CVD EXPERIMENTS 31 Classification of CVD Reactions 32 Thermodynamics			9.2	High Voltage Components	355
9.4 Evaporation/Sublimation Sources 9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY 15 REFERENCES 16 7 Chemical Vapor Deposition 17 Chemical Vapor Deposition 18 Jan-Otto Carlsson 19 Jan-Otto Carlsson 10 INTRODUCTION 20 IMPORTANT REACTION ZONES IN CVD 31 DESIGN OF CVD EXPERIMENTS 31 Classification of CVD Reactions 32 Thermodynamics	L		9.3	Gas Handling System	357
9.5 Sputtering Sources 9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY 10.1 REFERENCES 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY 13.0 SUMMARY 14.0 REFERENCES 15.0 APPLICATION ZONES IN CVD 15.0 INTRODUCTION 16.0 INTRODUCTION 17.0 INTRODUCTION 18.0 DESIGN OF CVD EXPERIMENTS 19.1 Classification of CVD Reactions 19.2 Addresion			9.4	Evaporation/Sublimation Sources	357
9.6 Plasma Uniformity 9.7 Plasma Generation Near the Substrate Surface 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY REFERENCES 7 Chemical Vapor Deposition Jan-Otto Carlsson 10 INTRODUCTION 20 IMPORTANT REACTION ZONES IN CVD 30 DESIGN OF CVD EXPERIMENTS 11 Classification of CVD Reactions 12 Adhering			9.5	Sputtering Sources	357
ti 9.8 Substrate Fixturing 10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications F 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY REFERENCES 7 Chemical Vapor Deposition Jan-Otto Carlsson ti 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 5 3.1 Classification of CVD Reactions 1.2 Adhesion			9.6	Plasma Uniformity	358
10.0 PROCESS MONITORING AND CONTROL					
10.0 PROCESS MONITORING AND CONTROL 10.1 Plasma 10.2 Substrate Temperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY REFERENCES 7 Chemical Vapor Deposition Jan-Otto Carlsson 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 1.2 Adhesion			9.8	Substrate Fixturing	358
10.2 Substrate Temperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY E REFERENCES F 1.0 Chemical Vapor Deposition Jan-Otto Carlsson 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 1.2 Adhesion	· ·	10.0	PROC	CESS MONITORING AND CONTROL	359
TO.2 Substrate remperature 10.3 Specifications 11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY REFERENCES 7 Chemical Vapor Deposition Jan-Otto Carlsson 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 1.2 Adhesion	A .		10.1	Plasma	359
11.0 PROBLEM AREAS 12.0 APPLICATIONS 13.0 SUMMARY REFERENCES T Chemical Vapor Deposition Jan-Otto Carlsson 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 3.2 Thermodynamics			10.2	Substrate Temperature	359
12.0 APPLICATIONS 13.0 SUMMARY REFERENCES 7 Chemical Vapor Deposition Jan-Otto Carlsson 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 1.0 Adhesion			10.3	Specifications	359
S 13.0 SUMMARY E REFERENCES T Chemical Vapor Deposition Jan-Otto Carlsson 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 1.2 Adhesion					
The References To Chemical Vapor Deposition Satisfies Jan-Otto Carlsson The Satisfies Jan-Otto C					
To Chemical Vapor Deposition Jan-Otto Carlsson 1.0 INTRODUCTION 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 3.1 Classification of CVD Reactions 3.2 Thermodynamics					
to 7 Chemical Vapor Deposition a Jan-Otto Carlsson ti 1.0 INTRODUCTION a 2.0 IMPORTANT REACTION ZONES IN CVD 3.0 DESIGN OF CVD EXPERIMENTS 5i 3.1 Classification of CVD Reactions ti 3.2 Thermodynamics		REF	ERENC	DES	365
The mical vapor Deposition Jan-Otto Carlsson	1				
Jan-Otto Carlsson 1.0 INTRODUCTION	•	7	Che	mical Vapor Deposition	374
tl 1.0 INTRODUCTION	_				
2.0 IMPORTANT REACTION ZONES IN CVD	•	4.0	_	·	074
fi 3.1 Classification of CVD Reactions			INTR	DDUCTION	3/4 375
fi 3.1 Classification of CVD Reactions	c				
tı 3.2 Thermodynamics		3.0			
2.2 Adhasian	***			The arms of the arms is a	//ن
t 3.3 Adnesion	tı			Inermodynamics	9/9
	ι		3.3	Agnesion	383

xxii Contents

4.0	MATERIALS DEPOSITED BY REACTIVE
	VAPOR DEPOSITION PROCESSES465
5.0	KEY ISSUES IN PLASMA-ASSISTED REACTIVE VAPOR
	DEPOSITION PROCESSES
	5.1 Plasma Volume Chemistry
	5.2 Type and Nature of the Bombardment
	of the Growing Film
6.0	PLASMA-ASSISTED DEPOSITION TECHNIQUES
	IN CURRENT USAGE
	6.1 Plasma-Assisted Chemical Vapor Deposition
	6.2 Sputter Deposition
	6.3 Activated Reactive Evaporation (ARE) 471
7.0	LIMITATIONS OF CURRENT PLASMA-ASSISTED
	TECHNIQUES
8.0	HYBRID PROCESSES
9.0	CONCLUSIONS
	ERENCES
	4/9
10	Deposition from Aqueous Solutions:
. •	
	An Overview480
	Morton Schwartz
1.0	INTRODUCTION480
2.0	GENERAL PRINCIPLES482
3.0	ELECTRODEPOSITION494
	3.1 Mechanism of Deposition
	3.2 Parameters500
4.0	PROCESSING TECHNIQUES
5.0	SELECTION OF DEPOSIT513
	5.1 Individual Metals513
	5.2 Alloy Deposition
6.0	SELECTED SPECIAL PROCESSES
	6.1 Electroless Deposition
	6.2 Electroforming 531
	6.3 Anodizing
	6.4 Plating on Plastics
	6.5 Plating Printed Circuit Boards
7.0	STRUCTURES AND PROPERTIES OF DEPOSITS548
8.0	SUMMARY 570
APPE	ENDIX A - Preparation of Substrates for Electroplating 571
APPE	ENDIX B - Representative Electroless Plating
	Solution Formulation
APPE	TNDIV O
	INDIX C - Comparison of Aluminum Anadizing Processes
	ENDIX C - Comparison of Aluminum Anodizing Processes (Types I, II and III)

ISBN % Appendix C





11	Advanced Thermal Spray Deposition	
	Techniques	591
	Robert C. Tucker, Jr.	
1.0	INTRODUCTION	501
2.0	EQUIPMENT AND PROCESSES	592
	2.1 Plasma Spray Process	592
	2.2 Detonation Gun Deposition Process	600
	2.3 High Velocity Oxy-Fuel Deposition	602
	2.4 Thermal Control	
	2.5 Auxiliary Equipment	604
	2.6 Equipment-Related Coating Limitations	605
3.0	TOTAL COATING PROCESS	606
	3.1 Powder	606
	3.2 Substrate Preparation	
	3.3 Masking	607
	3.4 Coating	
	3.5 Finishing	609
4.0	COATING STRUCTURE AND PROPERTIES	610
	4.1 Surface Macrostructure and Microstructure	
	4.2 Microstructure	
	4.3 Bond Strength	617
	4.4 Residual Stress	618
	4.5 Density	619
	4.6 Mechanical Properties	621
	4.7 Wear and Friction	627
	4.8 Corrosion Properties	634
	4.9 Thermal Properties	636
	4.10 Electrical Characteristics	638
5.0	SUMMARY	639
REF	ERENCES	639
40		
12	Non-Elemental Characterization of Films	
	and Coatings	643
	Donald M. Mattox	
1.0	INTRODUCTION	643
2.0	CHARACTERIZATION	645
3.0	FILM FORMATION	651
4.0	ELEMENTAL AND STRUCTURAL ANALYSIS	655
5.0	SOME PROPERTY MEASUREMENTS	656
	5.1 Adhesion	656
	5.2 Film Thickness	663
	5.3 Film Stress	

xxiv Contents

	5.4	Coefficient of Thermal Expansion	669
	5.5	Mechanical Properties	669
	5.6	Electrical R sistivity	670
	5.7	Temperature Coefficient of Resistivity (TCR)	670
	5.8	Electromigration	671
	5.9	Density	
	5.10	Porosity	672
	5.11	Chemical Etch Rate (Dissolution)	
6.0		MARY	
		CES	
	LNLIN	OEG	07 0
13	Nuc	leation, Film Growth, and Microstructural	
• -		lution	.681
		Joseph E. Greene	
4.0		•	601
1.0	INIF	ODUCTIONLEATION AND THE EARLY STAGES OF	00 1
2.0			600
		GROWTH	002
	2.1	Three-Dimensional Nucleation and Growth	
	2.2	Two-Dimensional Nucleation and Growth	
	2.3		702
3.0	COM	IPUTER SIMULATIONS OF MICROSTRUCTURE	704
		LUTION	/04
	3.1	Film Growth in the Ballistic Aggregation, Low-Adatom	=00
		Mobility, Limit	706
	3.2	Effects of Adatom Migration	708
4.0	MIC	ROSTRUCTURE EVOLUTION AND	
	STR	UCTURE-ZONE	710
5.0	EFFI	ECTS OF LOW-ENERGY ION IRRADIATION	
		ING FILM GROWTH	717
	5.1	Effects of Low-Energy Ion/Surface Interactions	
		on Nucleation Kinetics	717
	5.2		
		on Film Growth Kinetics	724
REF	EREN	CES	734
14	Mot	allurgical Applications	740
		Rointan F. Bunshah	
1.0		RODUCTION	
2.0		ROSION	
3.0	GAL	VANIC CORROSION	
	3.1	Galvanic Cells	742
40		AND GALVANIC SEDIES	744

	Contents	XXV
5.0	COATINGS FOR GALVANIC CORROSION	744
6.0	METHODS OF DEPOSITION OF METALLIC COATINGS .	
7.0	EXAMPLES OF CORROSION-RESISTANT COATINGS	
	7.1 Preamble	747
8.0	HIGH TEMPERATURE OXIDATION/CORROSION	750
9.0	FRICTION AND WEAR	
	9.1 Adhesive Wear	755
	9.2 Fretting Wear	755
	9.3 Abrasive Wear	756
	9.4 Fatigue Wear	756
	9.5 Impact Erosion Wear by Solid Particles and Fluids	756
	9.6 Corrosive Wear	
	9.7 Electric Arc Induced Wear	
	9.8 Solution Wear (Thermodynamic Wear)	757
10.0	COATINGS TO REDUCE FRICTION AND WEAR	757
	10.1 Friction	
	10.2 Lubrication	
	10.3 Wear	
REF	ERENCES	761
15	Characterization of Thin Films and Coatings Gary E. McGuire	763
1.0	INTRODUCTION	
2.0	SURFACE ANALYSIS TECHNIQUES	763
	2.1 Auger Electron Spectroscopy	763
	2.2 Photoelectron Spectroscopy	771
	2.3 Secondary Ion Mass Spectroscopy	777
	2.4 Rutherford Backscattering Spectroscopy	786
3.0	IMAGING ANALYSIS TECHNIQUES	
	3.1 Scanning Electron Microscopy	
	3.2 Transmission Electron Microscopy	802
4.0	OPTICAL ANALYSIS TECHNIQUES	
	4.1 Ellipsometry	
	4.2 Fourier Transform Infrared Spectroscopy	
	4.3 Photoluminescence Spectroscopy	
KEFE	ERENCES	819
16	Jet Vapor Deposition	822
,	Bret L. Halpern and Jerome J. Schmitt	
1.0	INTRODUCTION	822
2.0	PRINCIPLES AND APPARATUS OF JVD	
3.0	DISCUSSION	

C ntents

	3.1	Jet Structure, Behavior, and Vapor Transport	827
	3.2	Substrate Motion	830
4.0	EXA	MPLES OF JVD FILMS AND APPLICATIONS	831
	4.1	Cu, Au Multilayer Electrodes; Al, Al ₂ O ₃ Microlamina	tes 831
	4.2	PZT: Ferroelectric FRAM Nonvolatile Memories	832
	4.3	Electronic Grade Silicon Nitride	833
	4.4	Fiber Coating for Composite Materials	833
	4.5	Coating of Thermally Sensitive Membranes	834
	4.6	"Ceramic Host-Organic Guest" Films	834
	4.7	Polymer Deposition: Parylene	835
5.0	SUM	MARY	835
REF	EREN	CES	836
Inde	~		929